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LETTER TO THE EDITOR

Unresolved concerns about the "new SI"

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Dear Sirs,

The International Committee for Weights and Measures (CIPM) has proposed new definitions of four of the seven base units of the SI. The definitions of the proposed "new SI" have been published [1] and are available on the BIPM website [2], and have been the subject of lively discussions in the literature and in private communications. A number of concerns about the new SI have been raised in this journal and elsewhere [3–11]. We feel that these concerns have not been adequately addressed to date. Since the new SI definitions are to be formally proposed in a resolution to be considered in late October at the General Conference on Weights and Measures, this discussion has some urgency.

In this letter, we focus on the new SI definition of the kilogram and specifically that it fails to meet three of the criteria for a good reference quantity as presented by Mills et al. in Ref. [1] that (1) it "should preferably be as simple as possible both to comprehend and to realize"; (2) it "should be available to anyone at any time"; and (3) it "should be a true invariant".

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Comprehensibility

In Ref. [1], the definitions of the second, meter, and kilogram are explicated as follows:

> The effect of this definition is that the second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
> The effect of this definition is that the meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
> The effect of this definition, together with those for the second and the meter, is to express the unit of mass in terms of the unit of frequency through the fundamental equations $E = mc^2$ and $E = hv$ used to relate the frequency v equivalent to a mass m.

The definitions of the second and meter directly relate the defined unit to a corresponding physical quantity: second to period, meter to path length. The correspondence between mass and frequency is neither direct nor clear and will not be similarly comprehensible to non-specialists.

This inconsistency is not addressed by Mills et al. in Ref. [1]. In Part II of Ref. [11], Prof. Mills acknowledges that the atomic kilogram "is easier to comprehend and to teach", but states that the CIPM judges this factor to be outweighed by other advantages of the electronic kilogram.

Realization

"An essential aspect of the definitions of the units in the SI is the practical need to realize the definitions experimentally" [1]. While Mills et al. go on to assert that the definitions do not in and of themselves imply any specific

method of realization, the currently accepted *mise en pratique* of the electronic kilogram is the watt balance. While, as Prof. Mills also notes [11], the realization of any of the base units to the maximum possible accuracy and precision requires sophisticated measuring apparatus, the available method of realization of the electronic kilogram is qualitatively and computationally remote from the corresponding quantity, mass, in a way that the realizations of the units of time and length are not. This would be acceptable if there were no alternative definitions, but such definitions do exist [3, 8].

Availability

The criterion of availability of the reference quantity "to anyone at any time" is obviously an overstatement—it applies neither to *Le Grand K* nor to any of the proposed new reference masses. However, looking at the spirit of the criterion and defining "availability" broadly (but in our view realistically) to mean both physical and cognitive availability, the electronic kilogram is not clearly superior. The current standard and the atomic kilogram rely on physical artifacts that are either varying in time or difficult to realize, or both; however, both are *cognitively* available, in the sense that they can be readily comprehended by non-specialists. The same claim cannot be (and has not been) made for the electronic kilogram.

Invariance

The arguments over what are true invariants of nature for the purposes of defining base units tend to be physics- or chemistry-centric. Physicists are trained from their earliest studies to consider Planck's *constant* to be just that: both constant and invariant, and a standard based on it is undeniably appealing. To chemists, however, the mass of the carbon-12 atom is also fundamental, and the idea that under the new SI definitions the exact mass of a mole of carbon-12 (or any other substance) will never be known exactly is troubling.

Conclusion

There are reasonable arguments on both sides of the issue. Our main point here is that based on its published proposal and accounts of its deliberations, the CIPM has given only a limited hearing to alternatives to the proposed electronic kilogram and has not adequately responded to criticisms of it. Considering the significance of the first revision of the mass standard in well over a century, it seems reasonable, as we state in Part I of Ref. [11] "(to) hope that the scientific community has adequate opportunity to review and propose alternative definitions for the kilogram…before any changes are promulgated" and that a "delay in producing a 'New SI' seems to be a perfectly acceptable alternative for the present."

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